

ORIGINAL REPORT

## PREDICTORS OF PARTIAL WEIGHT-BEARING PERFORMANCE AFTER TOTAL HIP ARTHROPLASTY

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**Objective:** To determine which patient characteristics, post-operative characteristics, and walking features influence patients' partial weight-bearing performance after total hip arthroplasty.

**Design:** A descriptive prospective study.

**Patients:** Fifty patients with total hip arthroplasty were included; partial weight-bearing was performed at a 10% body weight target load ( $n=33$ ) and at a 50% body weight target load ( $n=17$ ).

**Methods:** Patient (age, gender, body weight, upper arm muscle strength) and postoperative (pain, fatigue, anxiety) characteristics, and walking features (step frequency, total walking time, total number of steps, walking aid) were measured postoperatively on day 7 (with and without a physical therapist) and on day 21 (at home). Multilevel regression analyses were conducted to identify determinants that influence partial weight-bearing.

**Results:** Gender (female) (regression coefficient  $B=8.18$ ,  $p=0.03$ ) and total walking time ( $B=0.58$ ,  $p<0.001$ ) were positively, and pain during walking was negatively ( $B=-2.43$ ,  $p=0.02$ ), associated with the mean peak load. For partial weight-bearing at 10% body weight, postoperative overall anxiety ( $B=6.40$ ,  $p=0.002$ ) and total steps ( $B=0.05$ ,  $p=0.02$ ) were positively associated with the percentage of steps above the target load. For partial weight-bearing at home, postoperative overall anxiety was negatively associated with the percentage of steps above the target load ( $B=-5.32$ ,  $p=0.001$ ).

**Conclusion:** Gender, pain during walking, walking time, postoperative anxiety and total number of steps influence the patient's partial weight-bearing performance.

**Key words:** weight-bearing, hip arthroplasty, physical therapy, rehabilitation, multilevel modelling.

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### INTRODUCTION

Postoperative gait training after lower limb surgery is often combined with weight-bearing restriction of the lower limb

to avoid complications during rehabilitation (1–7). The level of weight-bearing restriction is prescribed by the orthopaedic surgeon and can range from 10% to 50% of the patient's body weight (BW). The task of the physiotherapist (PT) is to instruct the patient to perform partial weight-bearing (PWB) at the prescribed target load. In a previous PWB study we found that patients loaded the operated leg higher and more frequently above the target load when a low target load (10% BW compared with 50% BW) was prescribed, and when patients walked at home without the supervision of a physical therapist (8). Other studies also showed that loading of the lower limb depends on the instruction method used and the target load (5, 6, 9–11). It can be assumed, however, that more factors than the instruction method used, target load and setting/time after surgery (hospital vs home), influence the load on the operated leg. Predictors of weight-bearing performance can help the PT to anticipate situations that might increase the risk of incorrect loading of the operated leg.

Three categories of determinants that may influence the patient's PWB performance can be distinguished; namely, patient characteristics, postoperative characteristics, and patient's walking features. The patient's age, BW and upper arm muscle strength can affect PWB because ageing decreases physical fitness, and walking with walking aids (compared with normal walking) is known to be physically demanding (12–16). When the prescribed target load is in percentage BW, heavier patients have to unload the leg more, and patients with less upper arm muscle strength can have difficulty unloading the leg. The postoperative state of the patient may also be of importance for the PWB performance. For instance, postoperative pain and anxiety may cause the patient to be more cautious about placing the foot on the ground. Furthermore, higher limb loads could occur when the patient is more fatigued. Certain walking features (e.g. the duration of walking or the type of walking aid used) might also affect the patient's loading of the operated leg. Therefore, when learning to walk with walking aids, patients are instructed to walk slowly and for short distances. However, when patients are feeling better during rehabilitation they may tend to walk for longer periods, which may increase the risk of higher limb loading.

The 3 categories are based more on logical reasoning than on scientific criteria because, to our knowledge, no studies have evaluated the relationship between patient characteris-

tics, or postoperative characteristics, or walking features and the patient's PWB performance. Only one study, by Chow et al. (7), evaluated patient characteristics and other factors that affected the patient's ability to perform PWB. The authors found that muscle power of the good limbs and mental state were significant factors, whereas, age, BW and type of surgery were not significantly related to PWB performance. Limitations of that study were that bathroom scales were used to measure weight-bearing during walking (which are not suitable for measuring vertical forces during walking (2, 17, 18), only a few steps were analysed, and parallel bars were used instead of commonly used walking aids (i.e. elbow crutches, standard walker). Therefore, in the present study we measured the amount of weight-bearing using a validated insole pressure system over a long-term period in the hospital, and at the patient's home/nursing home when patients were using a walker or elbow crutches.

The aim of the present study was to determine which patient characteristics, postoperative characteristics, and walking features influence the patient's PWB performance, measured over a long-term period in and outside the hospital using a validated insole pressure system. This knowledge can help the physician and PT to address factors that increase the risk of incorrect loading of the operated leg.

## PATIENTS AND METHODS

### Patients

Patients who participated in a previous study on weight-bearing were included in this study (8). Inclusion criteria were: primary unilateral total hip arthroplasty with trochanteric osteotomy, age between 40 and 80 years, and written informed consent. Exclusion criteria were: medical conditions or social problems due to which patients could not perform or could not be instructed to perform PWB (e.g. Parkinson's disease, epilepsy, and alcoholism), postoperative bed rest for more than 3 weeks, foot orthosis, foot deformities that needed special footwear, and a shoe size (European) smaller than 36 or larger than 45. The institutional review boards at each of the 2 participating hospitals approved the study.

A total of 50 patients were included in the study, of whom 33 (27 females, 6 males) performed PWB with a target of 10% BW and 17 (7 females, 10 males) with a target of 50% BW (Table I). Ninety-five patients were excluded for the following reasons: no written informed consent ( $n=34$ ), outside the age range ( $n=27$ ), medical or social problems ( $n=16$ ), problems related to feet or shoes ( $n=11$ ), and prolonged bed rest for 3 weeks ( $n=7$ ). Not all patients were measured at each condition (see procedure), mostly due to logistic reasons. Of the 33 patients with the 10% BW target, respectively, 25, 26, and 26 patients, and of the 17 patients with the 50% BW target, respectively, 11, 11,

and 16 patients were measured at condition 1, 2, and 3, respectively. Three patients, who were operated on in the hospital, which generally prescribes a 50% BW target load, were mobilized on a target load of 10% BW on postoperative orders of the surgeon.

### Procedure

The patients were instructed by a PT to perform PWB with a walker or elbow crutches (3-point gait (19)) depending on the walking ability of the patient. Instructions were given verbally, and verbal feedback was given during and/or after PWB. The patients were generally instructed with a 10% BW target load in one hospital, and with a 50% BW target load in the other participating hospital.

Prior to each weight-bearing measurement the insoles were calibrated using the Trublu calibration device (Novel<sub>GmbH</sub>, Munich, Germany) and a GDH 14AN digital manometer (Greisinger Electronic GmbH, Regenstauf, Germany). The pressure loads applied were 4, 7, and 10–60 N/cm<sup>2</sup> with intervals of 5 N/cm<sup>2</sup>. The Pedar system was placed in a custom-made vest together with a custom-made battery unit, consisting of 2 Sony NP750 Li-ion batteries, which was worn by the patient (8). An electronic device with an accelerometer was made to automatically start and stop the Pedar system so that only data were recorded when the patient was standing or walking. The accelerometer was fixed with adhesive tape on approximately the middle front part of the contralateral thigh. The Pedar system was turned on 1 h in advance (acclimatization period) and zero settings were carried out at  $t=0$  and  $t=1$  h (20). Data collection started after the second zero setting. Weight-bearing data during walking were collected over a period of approximately 5 h (from ~11.00 h to ~16.00 h) at a sample frequency of 50 Hz.

The weight-bearing measurements with the Pedar system were performed on day 7 ( $\pm 2$  days) postoperatively in the hospital when the patient walked with a PT (condition 1) or walked unsupervised (condition 2), and on day 21 ( $\pm 5$  days) postoperatively at the patient's home or in a nursing home (condition 3). Postoperatively in the hospital the patient's BW, upper arm muscle strength, pain, fatigue, and anxiety were measured on day 7 ( $\pm 2$  days). On day 21 ( $\pm 5$  days) postoperatively these patient variables were measured again at the patient's home (or in a nursing home), with exception of upper arm muscle strength.

### Dependant measures

**Partial weight-bearing.** The amount of weight-bearing was determined by measuring the peak load (N) of each step with the Pedar Mobile system (Novel<sub>GmbH</sub>, Munich, Germany), a portable insole pressure system, of which each insole (2 mm thick) contains 99 capacitance sensors. The Pedar Mobile system was adapted and validated to measure the vertical ground reaction force during walking over a long-term period (20, 21).

### Independent measures

**Patient characteristics.** The patient characteristics age and gender were registered, and BW was measured using an analogue scale (SECA 761, SECA, Hamburg, Germany). Isometric elbow extension force and isometric shoulder flexion force (N) for the left and right arm were measured with a hand-held dynamometer (22–26).

Table I. Patient characteristics (mean (standard deviation)) of the total hip patients with a trochanteric osteotomy included in the study with a target load of 10% and 50% body weight (BW)

	10% BW target		50% BW target	
	Men ( $n=6$ )	Women ( $n=27$ )	Men ( $n=10$ )	Women ( $n=7$ )
Age, years	58.0 (7.5)	65.4 (8.4)	53.1 (6.6)	64.6 (10.4)
BW, kg	79.0 (4.1)	74.6 (9.6)	87.5 (17.2)	68.7 (12.3)
Mean upper arm muscle strength, N	177.3 (30.6)	111.0 (28.4)	173.4 (42.9)	109.4 (16.4)
Mean upper arm muscle strength, N/BW, N	0.23 (0.03)	0.15 (0.04)	0.21 (0.05)	0.17 (0.04)

**Postoperative characteristics.** Overall postoperative pain (related to the operated leg) was measured with the dimension pain of the Dutch version of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), which uses a 5-point scale from 0 (=none) to 4 (=extreme) (27). Overall postoperative fatigue and anxiety were measured with the subscales for fatigue and anxiety of the Profile of Mood States (POMS), of which each scale consists of 6 mood-related adjectives that are rated on a 5-point scale from 0 (=not at all) to 4 (=extremely) (28, 29). To evaluate specifically the amount of pain (pain walking, pain standing), fatigue (fatigue walking) and anxiety (anxiety walking, anxiety falling, anxiety dislocating hip) during the period of the weight-bearing measurements an 11-point numerical rating scale (NRS) was used (30–32). After the weight-bearing measurements patients were asked to rate their pain during the periods of standing still and walking by giving a number between 0 (=no pain at all) and 10 (=the worst possible pain), and to rate their fatigue during walking by giving a number between 0 (=not tired at all) and 10 (=extremely tired). For anxiety (score 0=not afraid at all; score 10=extremely afraid) the questions were: how afraid are you to walk due to the pain of the operated leg, how afraid are you to fall during standing or walking, and how afraid are you that your hip may dislocate while turning around during walking.

**Walking features.** The step frequency (sec<sup>-1</sup>), the total walking time (min), and the total number of steps (*n*) were measured with the Pedar system. The information on which type of walking aid was used (elbow crutches or walker) was given by the PT or the patient.

**Data analysis**

Pedar-m Expert version 8.2 software was used to calculate the vertical force data from the Pedar system. Then, all Pedar data were imported in a custom-made Matlab program and were filtered using a low-pass Butterworth filter with a cut-off frequency of 40 Hz. A Matlab program was used to select the walking data within the data files, and to correct the walking data for offset drift (21). For each step the maximum peak load was determined. From these maximum peak loads, the mean and standard deviation (SD) peak load (% BW) and the percentage of steps above the target load were calculated for the 2 target loads (10% and 50% BW) and for each of the 3 conditions. We arbitrarily defined “above the target” as more than 20% BW for the 10% BW target, and more than 60% BW for the 50% BW target. The mean upper arm muscle strength was calculated from the measured left and right arm forces and normalized to BW. The mean and SD were calculated for all of the described variables. Paired *t*-tests and Wilcoxon signed-ranked tests using SPSS for windows (version 10; SPSS, Chicago, Illinois, USA) were applied to detect significant differences (level of significance set at *p* < 0.05) over time and between conditions.

Multilevel regression analysis was performed using MLwiN (version 1, London, UK) to analyse the relationship between the factors and the

patient’s PWB performance. First, univariate multilevel analyses were performed to analyse the relationship between each of the independent variables age, gender, BW, upper arm muscle strength, pain, fatigue and anxiety, and step frequency, total walking time, total number of steps and type of walking aid, and the dependent variables (Y) mean peak load (% BW) and percentage of steps above the target load. To assess whether the variables were associated with the conditions and the target load, interaction terms (condition × variable, and target × variable) were added to the models. For each univariate analysis we used the following 2-level multilevel linear regression model, with conditions set at level-1 (j) and individuals set at level-2 (i):

$$Y_{ij} = \beta_{0ij} + \beta_{1ij} \times (\Delta c1-c2)_{ij} + \beta_{2ij} \times (\Delta c2-c3)_{ij} + \beta_{3ij} \times target_{ij} + \beta_{4ij} \times variable_{ij} + \beta_{5ij} \times target \times variable_{ij} + \beta_{6ij} \times (\Delta c1-c2) \times variable_{ij} + \beta_{7ij} \times (\Delta c2-c3) \times variable_{ij} + \beta_{8ij} \times (\Delta c1-c2) \times target_{ij} + \beta_{9ij} \times (\Delta c2-c3) \times target_{ij}$$

The *a* in the model is the regression constant, the *β*s are the regression coefficients, and (Δ*c*1–*c*2) and (Δ*c*2–*c*3) are dummy variables, which means that their value is 0 or 1 depending on the condition of interest. For condition 1 dummy (Δ*c*1–*c*2) was 1 and dummy (Δ*c*2–*c*3) was 0, for condition 2 both dummy (Δ*c*1–*c*2) and dummy (Δ*c*2–*c*3) were 0, and for condition 3 dummy (Δ*c*1–*c*2) was 0 and dummy (Δ*c*2–*c*3) was 1. The variable target was coded as 0 for the 50% BW target and as 1 for the 10% BW target, the variable gender was coded 0 and 1 for male and female, respectively, and walking aid was coded as 0 and 1 for elbow crutches and walker, respectively. Variables were eliminated from the model using the backwards procedure with the level of significance set at *p* < 0.05. Secondly, multivariate multilevel analyses were performed with the variables from the univariate analyses that were found to be significant when *p* ≤ 0.1. For this multivariate analysis also backward regression was used with the level of significance set at *p* < 0.05. To permit valid assessments, both components of a significant interaction term had to be included in the model.

**RESULTS**

In the 10% BW target group 18% were men (Table I). In the 50% BW target group the men were younger (*p* = 0.01) and heavier (*p* = 0.03) than the women. The men had more upper arm muscle strength than the women in both the 10% BW target group (*p* < 0.001) and the 50% BW target group (*p* < 0.001). When corrected for BW this difference was only seen in the 10% BW target group.

During the postoperative period from day 7 (hospital) to day 21 (home) the overall pain decreased in the 10% BW target group, and the pain during walking decreased in both target groups (Table II). The patients overall fatigue and fatigue dur-

Table II. Postoperative characteristics (median (25<sup>th</sup>; 75<sup>th</sup> percentiles)) of the total hip patients with a trochanteric osteotomy with a target load of 10% and 50% body weight (BW) at day 7 (hospital) and day 21 (home) postoperatively

	10% BW target		<i>p</i> -value	50% BW target		<i>p</i> -value
	Day 7 ( <i>n</i> = 33)	Day 21 ( <i>n</i> = 30)		Day 7 ( <i>n</i> = 15)	Day 21 ( <i>n</i> = 16)	
Overall pain (WOMAC)	3 (1; 5.5)	1 (0; 3.25)	0.007*	4 (3; 6)	2.5 (1; 3.75)	0.05
Overall fatigue (POMS)	4 (2; 8)	1.5 (0.75; 3.25)	<0.03*	4 (3; 8)	1 (0; 2)	<0.001*
Overall anxiety (POMS)	2 (1; 4)	1 (0; 2)	0.25	3 (2; 5)	1 (0; 2)	<0.004*
Pain standing (NRS)	1 (0; 3)	0 (0; 1.25)	0.18	2 (1; 3)	0 (0; 1)	0.04*
Pain walking (NRS)	1 (0; 4)	0 (0; 2)	<0.004*	2 (1; 3)	1 (0; 2)	<0.007*
Fatigue walking (NRS)	4 (3; 6)	2 (0; 3.25)	<0.001*	3 (2; 5)	1 (0; 2)	<0.006*
Anxiety walking (NRS)	0 (0; 2)	0 (0; 0)	0.40	0 (0; 1)	0 (0; 0)	0.22
Anxiety falling (NRS)	0 (0; 4)	0 (0; 2)	0.35	1 (0; 2)	0 (0; 0)	0.03*
Anxiety dislocate hip (NRS)	0 (0; 0)	0 (0; 0)	0.32	0 (0; 0)	0 (0; 0)	0.36

\**p* < 0.05.

NRS: numerical rating scale; POMS: Profile of Mood States; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

ing walking was less at home compared with their stay in the hospital. Only in the 50% BW target group was a decrease seen in the patient's overall postoperative anxiety and the patient's anxiety about falling.

In the 10% BW target group the step frequency increased when the patients walked unsupervised compared with walking with a PT (Table III). An increase in step frequency was also found in this group when the patients walked at home. Both total walking time and total number of steps during the 5-h measurement period were larger at 3–4 weeks postoperatively.

*Relationships between patient characteristics, postoperative characteristics, and walking features and weight-bearing*

The variables age ( $p=0.24$ ), body weight ( $p=0.78$ ), upper arm force ( $p=0.21$ ), pain during standing ( $p=0.19$ ), fatigue ( $p=0.51$ ) and anxiety during walking ( $p=0.38$ ), anxiety to dislocate hip ( $p=0.15$ ) and walking aid ( $p=0.42$ ) were not significant ( $p>0.1$ ) in the univariate analyses with mean peak load as dependant variable and, therefore, not entered into the multivariate analyses. In the univariate analyses with percentage steps above the target load as dependant variable, the variables age ( $p=0.64$ ), body weight ( $p=0.80$ ), overall fatigue ( $p=0.14$ ), pain during standing ( $p=0.30$ ), fatigue ( $p=0.91$ ) and anxiety during walking ( $p=0.38$ ), step frequency ( $p=0.75$ ) and walking aid ( $p=0.35$ ) were not significant.

The multivariate multilevel regression analysis showed that mean peak load was negatively associated with pain during walking, and positively associated with total walking time (Table IV). Being a woman was a risk factor for increasing the mean peak load. The percentage steps above the target load was positively associated with postoperative overall anxiety when walking at a 10% BW target load, and negatively associated with postoperative overall anxiety when walking at home. Furthermore, for the 10% BW target load total steps during rehabilitation was a significant determinant for the percentage steps above the target load.

Table IV. Regression coefficients ( $p$ -values) for the relationship between the patient characteristics, postoperative characteristics, and walking features and weight-bearing; multivariate multilevel regression analysis

	Mean peak load (% BW)	% steps > target (% BW)
$\Delta c1-c2$ (0/1) <sup>a</sup>	2.03 (0.55)	5.98 (0.45)
$\Delta c2-c3$ (0/1) <sup>a</sup>	2.77 (0.23)	21.92 (<0.001)
Target (0/1) <sup>b</sup>	-22.80 (<0.001)	11.89 (0.37)
<i>Patient characteristics</i>		
Gender	8.18 (0.03)	ns
( $\Delta c1-c2$ ) $\times$ gender	ns	ns
Mean uams, N/BW, N	-	ns
<i>Postoperative characteristics</i>		
Overall pain (WOMAC)	ns	ns
Target $\times$ pain	ns	ns
Overall fatigue (POMS)	ns	-
( $\Delta c1-c2$ ) $\times$ fatigue	ns	
Overall anxiety (POMS)	ns	1.03 (0.58)
Target $\times$ anxiety	-	6.40 (0.002)
( $\Delta c2-c3$ ) $\times$ anxiety	-	-5.32 (0.001)
Pain walking (NRS)	-2.43 (0.02)	ns
Target $\times$ pain walking	3.20 (0.02)	ns
Anxiety falling (NRS)	ns	ns
Anxiety dislocate hip (NRS)	-	ns
<i>Walking features</i>		
Step frequency, sec <sup>-1</sup>	ns	-
Total walking time, min	0.58 (< 0.001)	ns
Total steps, $n$	ns	0.003 (0.80)
Target $\times$ total steps	-	0.05 (0.02)

<sup>a</sup>Condition 1: ( $\Delta c1-c2$ )=1 ( $\Delta c2-c3$ )=0; condition 2: ( $\Delta c1-c2$ )=0, ( $\Delta c2-c3$ )=0; condition 3: ( $\Delta c1-c2$ )=0, ( $\Delta c2-c3$ )=1.

<sup>b</sup>target=0 for 50 % BW and target=1 for 10% BW.

BW: body weight; NRS: numerical rating scale; ns: not significant ( $p>0.05$ ); POMS: Profile of Mood States; uams: upper arm muscle strength; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

DISCUSSION

The principal finding of the present study was that gender (female) and total walking time were positively, and pain during

Table III. Walking features step frequency, total walking time and total number of steps (mean (standard deviation)) of the total hip patients with a trochanteric osteotomy with a target load of 10% and 50% body weight (BW) for the 3 conditions

	10% BW target				
	C1 (n=25)	C2 (n=26)	C3 (n=26)	C1-C2 (n=20) $p$ -value	C2-C3 (n=23) $p$ -value
Step frequency, sec <sup>-1</sup>	0.36 (0.08)	0.38 (0.06)	0.48 (0.09)	0.01*	<0.001*
Total walking time, min	3.9 (2.3)	6.2 (4.4)	15.3 (8.9)	0.14	<0.001*
Total steps, $n$	70.1 (39.7)	116.5 (75.9)	394.5 (251.4)	0.09	<0.001*
	50% BW target				
	C1 (n=11)	C2 (n=11)	C3 (n=16)	C1-C2 (n=8) $p$ -value	C2-C3 (n=10) $p$ -value
Step frequency, sec <sup>-1</sup>	0.41 (0.13)	0.44 (0.15)	0.50 (0.10)	0.68	0.10
Total walking time, min	5.0 (3.2)	6.5 (2.8)	17.1 (11.4)	0.53	0.03*
Total steps, $n$	101.8 (58.9)	162.5 (113.1)	486.6 (378.6)	0.36	0.04*

\* $p<0.05$ .

C1: partial weight-bearing in hospital with a physiotherapist; C2: partial weight-bearing in hospital without a physiotherapist; C3: partial weight-bearing at home.

walking was negatively associated with the mean peak load during partial weight-bearing. For PWB at 10% BW, postoperative overall anxiety and total steps were positively associated with the percentage of steps above the target load. For PWB at home, postoperative overall anxiety was negatively associated with the percentage of steps above the target load.

#### *Patient characteristics*

Gender (female) was positively associated with the mean peak load, which means that women tend to load the leg more than men. Therefore, it seems that gender is an important factor for PWB performance when using (verbal) feedback. However, no literature was found on gender difference in feedback-receiving motor learning. An explanation could be that the men in our study had more upper arm strength than the women. When we corrected for BW, this difference was not significant in the 50% BW target group, probably due to small group size.

The patient characteristics age, BW and upper arm muscle strength were not related to the patient's PWB performance, which was also reported by Chow et al. (7) with exception of upper arm muscle strength. It is known that ageing results in a decrease in physical and mental condition (25, 33–35). However, this age effect is mostly seen when comparing younger (20–30 years) and older (60–75 years) subjects. In our study and that of Chow et al. (7) a group of hip patients was evaluated that had a relatively small age range and, therefore, probably no correlation was found between age and weight-bearing. We expected that the relationship between upper arm muscle strength and BW would influence the PWB, i.e. higher limb loads during PWB will probably occur when a patient has poor upper arm muscle strength and is also heavy and that a patient with normal upper arm muscle strength who has a relatively low BW will load the limb less. However, we found no relationship between normalized upper arm muscle strength and mean peak load or percentage of steps above the target. A possible explanation for the lack of correlation between upper normalized arm muscle strength and weight-bearing could be that the patients who had more upper arm muscle strength were also heavier. Because patients were instructed to load their leg at a percentage of their BW, heavier patients have to unload their leg more (absolute load) than patients with a lower BW, which costs more upper arm muscle strength. This was confirmed by the fact that upper arm muscle strength normalized for BW also showed no relationship with the weight-bearing outcome measures. The patients in the study of Chow et al. (7) had a much lower BW (43–44 kg) than our patients (69–88 kg), which might explain why Chow et al. (7) found that arm strength was related to weight-bearing. Another explanation could be that our weight-bearing measurements were performed in a non-controlled environment (i.e. outside a laboratory), and that although the patient had sufficient upper arm muscle strength to load the leg correctly he/she did not load the leg at the prescribed target load. Further (laboratory) research should clarify whether a minimum upper arm muscle strength is needed for weight-bearing at a specific target load.

#### *Postoperative characteristics*

Among the postoperative status factors, pain during walking was negatively correlated with the mean peak load. This con-

firms our expectation that patients who have more pain would unload their leg (voluntarily) more than patients who have less to no pain. Koval et al. (36) have shown that patients voluntarily restrict the loading of the leg after operative treatment of a fracture. Also, Vasarhelyi et al. (37) stated that increasing levels of load might be a function of postoperative pain, as their young patients loaded their leg more when they had a slight decrease in pain; however, in their older patients, a substantial decrease in pain did not change the variance in the magnitude of load bearing. Although pain could restrict the loading of the leg, we think that pain intensity is not a good instrument to unload the leg to a specific target load (e.g. 10% BW) and during the entire recovery period of 6–8 weeks. First, because pain during walking was not negatively associated with weight-bearing for the 10% BW target load. Secondly, the voluntary unloading of the patients in the study by Koval et al. (36) was 51% BW at one week and 65% BW at 3 weeks postoperatively. Moreover, pain varies between total hip patients, and most patients in our study had little to no pain 3 weeks after the total hip operation and still had to restrict weight-bearing to either 10% or 50% BW for another 3 weeks.

Patients can become fatigued during PWB, which might lead to higher loads, because walking with assistive devices is physically demanding (12–16). However, we did not find a (positive) correlation between fatigue and weight-bearing. This may indicate that weight-bearing is not influenced by the patient's level of fatigue.

Postoperative anxiety can influence the patient's weight-bearing performance as patients might be more careful in placing their foot on the ground or walk less, which could decrease the risk of high weight-bearing loads. However, contrary to our expectations, a positive correlation was found between postoperative overall anxiety and percentage of steps above the target at a 10% BW target load. The positive correlation between anxiety and weight-bearing could indicate that the patients loaded their operated leg more to gain more balance. At home, a negative correlation was found, which indicates that patients tend to increase weight-bearing when they are less anxious.

#### *Walking features*

From the walking features, an increase in walking time led to a higher mean peak load. Also, an increase in total number of steps led to a higher percentage of steps above the target for the 10% BW target load. The relationship between walking time and weight-bearing, and total number of steps and weight-bearing can be explained by a higher chance of loading the leg more when patients are walking more. However, it should be noted that, besides the relationship that patients load the leg more due to more walking, patients may also load the leg more because they are more confident and walk more because they are more confident. In this case, there is no direct correlation between walking and weight-bearing, as both, separately, increase due to another factor. Previous studies found that an increase in step frequency or walking cadence resulted in an increase in the vertical ground reaction force and plantar pressures (38–40). Martin & Marsh (41), however, found little change in ground reaction

forces while changing the step frequency, which they explained by the fact that they controlled speed during the measurements. In our study no significant relationship was found between step frequency and weight-bearing.

No correlation was found between type of walking aid and weight-bearing. Youdas et al. (42) found differences in walking speed and cadence with different types of assistive devices; however, they did not evaluate a standard walker or elbow crutches. Our results suggest that PWB with a walker or elbow crutches does not affect the weight-bearing performance of the patient.

In our previous study we found that the prescribed target load influenced the weight-bearing of the patients; the 10% BW target load had a lower mean peak load and had more steps above the target load than the 50% BW target load (8). In the regression models we found that target was an effect-modifier for pain during walking, anxiety and total steps, which means that a significant correlation with the dependent variable was found for the 10% BW target load but not for the 50% BW target load. Besides the differences in relationships for the 2 target loads, we also found that certain independent variables were correlated with the mean peak load but not with the percentage of steps above the target or vice versa. Therefore, one has to be aware that the interpretation of the relationships found depends on the selected PWB outcome measure.

The limitations of our study include the number and selection of patients evaluated. Using multilevel analysis with repeated measurements we efficiently used the number of measurements to increase the data-set. Although weight-bearing measurements were repeated at 3 conditions, the correlation between the independent and the dependent variables was not equally strong for each of the 3 conditions, which might explain why certain correlations were not found. Also, weight-bearing was not assessed for every patient at each of the 3 conditions, which reduced the number of measurements. Exclusion of less fit patients, resulting in a relatively small homogenous group, could have influenced the results regarding not finding relationships between weight-bearing and age, upper arm muscle strength and fatigue. Therefore, our results should be interpreted with some caution, and longitudinal studies with larger sample sizes are needed to confirm our findings.

In clinical practice it is important for the PT to know which factors influence the patient's PWB performance, so that they can anticipate situations that might increase the risk of incorrect loading of the operated leg. Our results indicate that there is a risk of increase in weight-bearing when the patient is a woman. Also, anxiety may be an important factor that can lead to an increase in percentage of steps above the prescribed target load. Furthermore, an increase in limb load is more likely to occur when a patient walks longer. Additionally, when a 10% BW target load is prescribed more steps will be loaded above the target load when a patient takes more steps. Contrary to our expectations, upper arm muscle strength did not influence PWB, and an increase in anxiety did not result in a decrease in PWB. In view of our results, we think that pain intensity is not a good instrument to unload the leg to a specific target load during an entire recovery period lasting 6–8 weeks.

In conclusion, although limited weight-bearing is often trained after lower limb surgery to avoid complications, little to no information is available on factors that influence partial weight-bearing. Our study shows that gender, pain during walking, walking time, postoperative overall anxiety and total number of steps influence the PWB performance of patient with a total hip arthroplasty. These preliminary results can help PT to anticipate situations that might increase the risk of incorrect loading of the operated leg. Given the limited size of our study population, longitudinal studies with larger sample sizes are needed to confirm these findings.

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